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"Rotary displacement machine"

This invention relates to a rotary displacement machine.

"Displacement machine" is given to mean a machine in which two profiled members have annular profiles that mesh with one another defining variable volume chambers - or capsules - between them.

The invention relates more particularly to machines in which one of the profiles is inside the other, one being m-lobed and the other (m-1)-lobed, where the integer m is greater than or equal to 2.

The term "m-lobed" profile is used to denote an annular profile defined by a pattern forming a lobe dome and a lobe hollow, this pattern being repeated m times around the centre of a pitch circle associated with the profile.

An (m-1)-lobed profile is an annular profile defined by a pattern forming a lobe dome and a lobe hollow, this pattern being repeated (m-1) times around the centre of a pitch circle associated with the profile.

The profiles cooperate with each other through a sort of meshing during which their respective pitch circles roll on each other at a rolling point that is fixed relative to a connecting member relative to which the two profiled members turn, each on an axis passing through the centre of its pitch circle.

Displacement machines can for example be hydraulic motors, hydraulic pumps, compressors or expansion motors.

EP-A-0870926 describes a displacement machine of the so-called "gerotor" type, that is, in which the inner profiled member is (m-1)-lobed. The geometry of this machine is conventional in itself. The document relates more particularly to the creation of a given play between the profiles.

EP-539273-B1 describes various displacement machines, and in particular machines with two lobes on the inner profile and three on the outer profile, and conversely machines with three lobes on the inner profile and just two lobes on the outer profile.

US-A-1 892 217 describes the Moineau pump. Instead of having cylindrical profiles, this gerotor type machine has helical profiled members with a total helix angle of several revolutions. The chambers are formed at an axial end of the profiled members and are then transported without any variation in volume to the other end, where they disappear. Two remarkable results are obtained: the distribution is simplified in the extreme as the chambers simply have to open freely on intake at one end and on discharge at the other end. Furthermore, the flow rate is completely constant.

Numerous documents such as US-A-6 106 250, DE 42 04 186 A1, EP 0 094 379 B1, DE 44 25 429 A1 and EP 0 799 966 A2 describe machines with a Wankel type geometry, that is, with a generally triangular rotor with curved surfaces effecting a planetary movement in a bi-lobed stator.

WO 93/08402 describes improvements to the Moineau pump.

In the prior art the profiles are often only conjugate in an approximate way. Flexible sealing members are provided to compensate for the approximations in conjugation. For example, in the Moineau pump (US-A-1 892 217), the inner lining of the outer profiled member is flexible. In most Wankel type machines, retractable segments are provided at the ends of the triangular rotor and sometimes also at the vertices of the lobes of the outer profiled member. Even in the best known machines, the leak paths between successive chambers are

relatively short and there are problems in switching a chamber from intake to discharge.

The object of this invention is to find an improvement with regard to the quality of the contact between the profiles, the switching between intake and discharge by the distribution system, and the progressiveness of the appearance and disappearance of each chamber.

More particularly, a family of geometries has been found according to the invention, together with associated methods of determination, as a result of which the profiles are in osculating contact in the stages of appearance and disappearance of a chamber. Osculating contact is given to mean a point of contact at which the curvatures of the two profiles are continuous, equal and in the same direction. On the appearance of a chamber, the osculating contact splits into two contacts between which the chamber forms. On the disappearance of a chamber, two separate contacts come together increasingly until they become a single, and then simple, osculating contact.

According to the invention, the displacement machine comprising:

- two profiled members, inner and outer respectively, which respectively have an annular inner profile and an annular outer profile,
- a connecting member connected rotatably to each of the two profiled members along a respective axis of rotation,

and in which:

- one of the profiles is m-lobed and the other is (m-1)-lobed, and they are defined around the axis of rotation of their respective profiled member by m and (m-1) respectively, pattern(s) comprising a lobe dome arc and a lobe hollow arc,
- each profile is the envelope of the other during relative rotations of the profiled members around their respective axis of rotation with meshing of their profiles, which define the chamber contours between them, and rolling without sliding between two

pitch circles centred on the respective axes of rotation,

is characterised in that the relative positions of the profiled members for which a point of contact between the profiles is located on the tangent to the two pitch circles at their mutual rolling point, the profiled members have at said point of contact equal continuous curvatures in the same direction with said rolling point as their common centre.

Preferably, the displacement machine is characterised in that

- points M on a first of the two arcs of the m-lobed profile being defined by two functions $\rho(\delta)$ and $\sigma(\delta)$ connecting the parameters ρ and σ to the parameter δ seen as a coordinate on the arc and which are:

ρ: measured along the normal to the arc at point M, the distance between point M and the middle N between the two points of intersection P and D, proximal and distal respectively, of the said normal with the pitch circle with centre O of the m-lobed profile, and with a radius assumed equal to 1, the proximal point of intersection P being located between point M on the given arc and the distal point of intersection D,

δ: angular half-distance between D and P relative to the centre O, measured clockwise,

σ: polar angle of the proximal point of intersection P relative to O, minus δ,

the functions $\rho(\delta)$ and $\sigma(\delta)$ having a domain of between $\delta=0$ and $\delta=\pi$,

- two arcs of the pattern of the (m–1)-lobed profile are a proximal conjugate arc and a distal conjugate arc defined below in a Cartesian reference system with their origin at the centre O of the pitch circle associated with the m-lobed profile:

a) proximal conjugate arc:

$$x_{CjP}(\delta) = (1 + (\sin(\delta) - m\rho(\delta))\sin\left(\frac{\delta - m\sigma(\delta)}{m-1}\right) + (m-1)\cos(\delta)\cos\left(\frac{\delta - m\sigma(\delta)}{m-1}\right))/m$$

$$y_{CjP}(\delta) = ((\sin(\delta) - m\rho(\delta))\cos\left(\frac{\delta - m\sigma(\delta)}{m-1}\right) - (m-1)\cos(\delta)\sin\left(\frac{\delta - m\sigma(\delta)}{m-1}\right))/m$$

b) distal conjugate arc:

$$x_{CjD}(\delta) = (1 + (\sin(\delta) + m\rho(\delta))\sin\left(\frac{\delta + m\sigma(\delta)}{m-1}\right) + (m-1)\cos(\delta)\cos\left(\frac{\delta + m\sigma(\delta)}{m-1}\right))/m$$

$$y_{CjD}(\delta) = (-(\sin(\delta) + m\rho(\delta))\cos\left(\frac{\delta + m\sigma(\delta)}{m-1}\right) + (m-1)\cos(\delta)\sin\left(\frac{\delta + m\sigma(\delta)}{m-1}\right))/m$$

If one refers to the mathematical complexity associated with the design of displacement machines, the solution proposed according to the invention is remarkably simple.

A first arc of one of the profiles and a pitch circle for that profile can be chosen, and then the arc is defined mathematically in the very specific parameterisation that has been devised according to the invention, by establishing the two functions $\rho(\delta)$ and $\sigma(\delta)$. This initially chosen arc is known as the "given arc".

Directly thereafter, by application of the formulae according to the invention, the proximal conjugate arc and the distal conjugate arc are obtained by their Cartesian coordinates having their origin at the centre O of the pitch circle associated with the given arc. The conjugate profile of the given arc is obtained by concatenation of the proximal conjugate arc and the distal conjugate arc. Concatenation means that the two arcs, each taken in the entirety of its length corresponding to a variation of δ over the interval $[0,\pi]$ are connected end to end by the points at which $\delta = 0$. The formulae automatically realise that the two arcs, proximal and distal, have not only the same tangent but also the same curvature at their connection point and this curvature is also the same as the curvature at a corresponding extremity of the given arc. The normal to the conjugate profile at the connection point is tangent to the respective pitch circles of the chosen arc and the conjugate profile at the rolling point of these circles on each other. The radius of the pitch circle of the given arc having been chosen arbitrarily as equal to 1, the radius of the pitch circle of the conjugate profile is equal to $(m-1)/m$. The pitch circle of the conjugate profile is therefore determined. The complete conjugate profile is then obtained by

concatenating (m-1) times the pattern made up of the proximal conjugate arc and the distal conjugate arc over (m-2) rotations at an angle of $2\pi/(m-1)$ around the centre O' of the pitch circle of the conjugate profile.

For the second arc of the m-lobed profile, or complementary arc of the given arc, there are two possible scenarios depending on the geometry chosen for the given arc. According to the invention, a distinction is made between these two scenarios according to the value of the derivative ρ' of the function ρ relative to its variable δ at points 0 and π.

In a first scenario, the derivative ρ' relative to δ where $\delta = 0$ and $\delta = \pi$ satisfies the following strict inequalities:

$1/m > \rho'(0) > 0$

$-1/m < \rho'(\pi) < 0$

the m-lobed profile is then inside the (m-1)-lobed profile, and

the m-lobed profile is complemented by a proximal complementary arc defined by its coordinates in the said Cartesian reference system:

$$x_{CpP}(\delta) = ((2\sin(\delta) - m\rho(\delta))\sin\left(\frac{2\delta}{m} - \sigma(\delta)\right) + m\cos(\delta)\cos\left(\frac{2\delta}{m} - \sigma(\delta)\right))/m$$

$$y_{CpP}(\delta) = ((2\sin(\delta) - m\rho(\delta))\cos\left(\frac{2\delta}{m} - \sigma(\delta)\right) - m\cos(\delta)\sin\left(\frac{2\delta}{m} - \sigma(\delta)\right))/m$$

A first class of machines according to the invention is thus obtained, in which the inner profile has one more lobe than the outer profile.

For this first class of machines, the two conjugate arcs, proximal and distal respectively, defined by the formulae according to the invention, are positioned radially outside the given arc, and the complementary arc of the given arc complements the m-lobed profile inside the conjugate, (m-1)-lobed, profile.

In a second scenario, the derivative ρ' relative to δ where $\delta = 0$ and $\delta = \pi$ satisfies the following strict inequalities:

$-1/m < \rho'(0) < 0$

$1/m > \rho'(\pi) > 0$

The m-lobed profile is outside the (m-1)-lobed profile;

and

the m-lobed pattern is complemented by a distal complementary arc defined by the following set of Cartesian coordinates around the centre O:

$$x_{CpD}(\delta) = ((2\sin(\delta) + m\rho(\delta))\sin\left(\frac{2\delta}{m} + \sigma(\delta)\right) + m\cos(\delta)\cos\left(\frac{2\delta}{m} + \sigma(\delta)\right))/m$$

$$y_{CpD}(\delta) = (-(2\sin(\delta) + m\rho(\delta))\cos\left(\frac{2\delta}{m} + \sigma(\delta)\right) + m\cos(\delta)\sin\left(\frac{2\delta}{m} + \sigma(\delta)\right))/m$$

This gives a second class of machines in which the conjugate, (m-1)-lobed, profile is automatically defined as being radially inside the m-lobed profile to which the given arc belongs.

The formulae above, whether they relate to the first or second class of machines, do not require that the given arc has an axis of symmetry.

If the given arc does not have an axis of symmetry, machines are obtained in which the chamber growth and shrinkage processes are not symmetrical to each other.

Other specific features and advantages of the invention will become apparent from the description below, which relates to non-limitative examples.

In the appended drawings:

- figure 1 is a front view of the profiled members, showing certain specific geometric features of a machine in the first class according to the invention;
- figures 2A to 2F are views analogous to figure 1, but on a smaller scale, showing six successive states of the machine in figure 1;
- figure 3 is a view analogous to figure 1 but relating to a machine in the second class;
- figures 4A to 4F are views analogous to figure 3, but on a smaller scale, showing six successive states of the machine;

- figure 5 is a geometric construction illustrating the determining of the parameters of the profiles according to the invention;
- figures 6A, 6B and 6C show the large-scale detail of the profiles passing through osculation, in the example in figure 1, figure 6B relating to the osculation, and figures 6A and 6C being offset by a rotation of three degrees of the inner profile in either direction;
- figures 7A and 7B show, in two different states, a machine in the first class according to the invention with a bi-lobed inner profile;
- figures 8A and 8B show, in two different states, a machine in the first class according to the invention with a tri-lobed inner profile;
- figures 9A and 9B show, in two different states, a machine in the first class according to the invention with an eight-lobed inner profile;
- figures 10A to 10I show nine different geometries for a machine in the first class according to the invention, with a four-lobed inner profile;
- figures 11A, 11B and 11C show three different geometries for a machine in the first class according to the invention, with a five-lobed inner profile;
- figure 12 is a view of the machine in figure 11B on an enlarged scale, with schematisation of certain means of distribution;
- figure 12A is a detailed view showing a variant for the distribution system in the embodiment in figure 12;
- figure 13 is an analogous view to figure 12 but relative to the machine in figure 1;
- figure 14 is a schematic perspective view of a machine in which the profiled members

are helical with successive profiles according to figure 1;

- figure 15 is a schematic axial sectional half-view of a machine according to the invention;
- figure 16 is a partial axial sectional view of a machine according to the invention, with variable capacity;
- figures 17A and 17B show, in two different states, a machine in the second class according to the invention, with a one-lobed inner profile;
- figures 18A and 18B show, in two different states, a machine in the second class according to the invention, with a bi-lobed inner profile;
- figures 19A and 19B show, in two different states, a machine in the second class according to the invention, with a tri-lobed inner profile;
- figures 20A and 20B show, in two different states, a machine in the second class according to the invention, with a four-lobed inner profile;
- figures 21A and 21B show, in two different states, a machine in the second class according to the invention, with a five-lobed inner profile;
- figures 22A and 22B show, in two different states, a machine in the second class according to the invention, with a seven-lobed inner profile;
- figures 23A and 23B show, in two different states, a machine in the second class according to the invention, with a tri-lobed inner profile in a different geometry to the geometry in figures 19A and 19B;
- figures 24A and 24B are analogous to figures 23A and 23B respectively, but in yet another geometry;
- figures 25A and 25B are analogous to figures 23A and 23B respectively, but in yet another geometry;

- figures 26A and 26B show, in two different states, a machine in the second class according to the invention, with a bi-lobed inner profile but in a different geometry to the geometry in figures 18A and 18B, more particularly appropriate for the production of a compressor;
- figures 27A and 27B are analogous to figures 26A and 26B, but with asymmetrical profiles;
- figures 28A to 28F very schematically show, in six different states, a first embodiment of a multistage machine according to the invention, with a bi-lobed intermediate profiled member mounted between two tri-lobed profiles; and
- figures 29A to 29F very schematically show, in six different states, a second embodiment of a multistage machine according to the invention, with a tri-lobed intermediate profiled member mounted between two bi-lobed profiles.

In the example shown in figure 1, the machine comprises a profiled inner member 1 and a profiled outer member 2 that surrounds the profiled inner member 1.

The profiled inner member 1 has on its outer circumference a lobed profile 3 and the profiled outer member 2 has on its inner circumference a lobed profile 4 that surrounds the lobed profile 3 of the profiled inner member 1.

One of the profiles has one more lobe than the other. In the example in figure 1, which corresponds to what is known within the scope of the invention as a machine in the first class, the inner profile 3 has one more lobe than the outer profile 4. It is said that the inner profile 3 is m-lobed and that the outer profile 4 is (m-1)-lobed.

In the example in figure 1, m = 6, so that the inner profile 3 is six-lobed and the profile 4 of the profiled outer member 2 is five-lobed.

Each profile 3, 4 has rotation symmetry around the origin of the pitch circle associated with it, and the order of this symmetry is the number of its lobes.

Thus, the profile 3 of the inner member 1 has symmetry of order 6 around a centre O, and the profile 4 of the profiled outer member 2 has symmetry of order 5 around a centre O'.

There is a distance 1/m along an axis Ox between the centres O and O'.

Each lobe is defined by a respective pattern, the profile 3 or 4 being defined by repeating its respective pattern m times or (m-1) times respectively by rotation of $2\pi/m$ or $2\pi/(m-1)$ respectively around the centre of symmetry O or O' respectively.

Each of the profiles 3, 4 has a pitch circle 6, 7 with a centre O and O' respectively. The radii of the pitch circles are proportionate to the number of lobes of the profile with which they are respectively associated, so that they are tangent to each other at a point R located on the axis Ox.

Each pattern is made up of a "lobe dome" and a "lobe hollow". A "lobe dome" is a protruding part, i.e. a part radially distant from the centre for the inner profile and a part radially close to the centre for the outer profile. Conversely, a "lobe hollow" is a generally concave part, i.e. close to the centre for the inner profile and distant from the centre for the outer profile. The highest point of a lobe dome is known as the "lobe vertex" and the deepest point of a lobe hollow is known as the "lobe bottom".

In the example shown, the profiles have reflection symmetry relative to radii passing through the lobe vertices and lobe bottoms, but this symmetry is not vital to the invention, as will be seen below.

The m-lobed profiled member 1 is articulated to a connecting member, not shown in figure 1, along an axis of rotation that coincides with the centre O. Similarly, the

(m-1)-lobed profiled member 2 is articulated to the connecting member along an axis of rotation that coincides with the centre O' of its pitch circle.

In operation, the two profiled members effect a rotation around their respective axis of rotation O, O' relative to the connecting member, in such a way that the two pitch circles 6, 7 roll on each other at point R, which remains immobile relative to the connecting member. As a result, the reference Ox, Oy is immobile relative to the connecting member, as are the centres O and O'. Moreover, the description given thus far also implies that the m-lobed profiled member 1 executes (m-1)/m of a revolution when the (m-1)-lobed profiled member 2 effects a complete revolution.

During this combined movement of the two profiled members 1 and 2, each lobe dome on each profile 3 or 4 is in contact with the other profile. In a region situated to the right of figure 1, and more specifically radially beyond a common tangent T to the two pitch circles 6 and 7 at their mutual rolling point R, each lobe dome of one of the profiles forms a unique contact with a lobe dome of the other profile. Such a unique contact C_1 is in particular shown. On the other side of the common tangent T, each lobe dome of one of the profiles is in contact with a lobe hollow of the other profile. Contacts C_3, C_5, C_7 and C_9 can thus be seen between a dome of the m-lobed profile and a hollow of the (m-1)-lobed profile, which alternate with contacts C_4, C_6 and C_8 between a dome of the (m-1)-lobed profile and a hollow of the m-lobed profile.

The trajectories of the contact points relative to the connecting member represented by the reference Oxy are known as curves of action. In the region situated to the right of the common tangent T, there is a single curve of action CA_1, the extremities of which are points B_N and B_M situated on the tangent T. On the other side of the tangent T, there are two curves of action CA_2 and CA_3, which correspond to the trajectory of the points of contact formed by the domes of the m-lobed profile 3 and by the points of contact

formed by the domes of the (m-1)-lobed profile 4 respectively. The extremities of the two curves of action CA_2 and CA_3 are also formed by points B_N and B_M, which will be referred to as bifurcation points of the curves of action.

In the specific situation shown in figure 1, one of the points of contact, denoted by C_2, coincides with the bifurcation point B_N. This point of contact marks the boundary between a hollow and a dome on one side of the pattern of each of the two profiles. In another situation, shown in figure 2C, a point of contact coincides with the bifurcation point B_N and marks the boundary between a hollow and a dome on another side of the pattern of each of the two profiles.

According to an important specific feature of this invention, the profiles, which are determined in a manner that will be described below, define an osculating contact between the two profiles when the point of contact is made at B_N or B_M. This means that the profiles have at their point of contact located at B_N or B_M, not only a common tangent, but also equal continuous curvatures in the same direction.

Furthermore, the centre of curvature common to both profiles in their osculation coincides with the rolling point R, so that their radius of curvature is equal to the distance between R and B_N, or B_M respectively. This osculation ensures contact between the two profiles that is of an excellent quality.

When the profiled member 1 rotates around its centre O in the direction shown by the arrow F, the contact such as C_1 follows the curve of action CA_1 until it coincides with the bifurcation point B_N to form the aforementioned osculation. From there, the contact splits into two separate contacts each following one of the two curves of action CA_2 and CA_3. Then these two separate contacts merge once more into an osculating contact at the bifurcation point B_M.

Capsules - or chambers - are defined between the two profiles 3 and 4 and between the successive points of contact.

In the situation shown in figure 1, a chamber is appearing at the point of contact C_2. During the rotation of the profiled inner member 1 and the correlative rotation of the profiled outer member 2, the chamber appearing at the bifurcation point B_N will successively form the chambers V_1, V_2, ... V_9. Chambers V_1 to V_4 are in the volume growth phase whilst chambers V_5 to V_9 are in the volume shrinkage phase. The growth phase extends over almost an entire revolution, as does the shrinkage phase, so that the complete cycle extends over slightly less than two revolutions. If the machine is a hydraulic motor, the hydraulic fluid is at high pressure in chambers V_1 to V_4 in the growth phase, and at low pressure in chambers V_5 to V_9 in the shrinkage phase. The chambers in the growth phase and under pressure alternate with the chambers in the shrinkage phase and not under pressure. If the hydraulic machine operates as a pump, the same alternation is seen, except that the chambers in the shrinkage phase are under pressure and the chambers in the growth phase are taking in the fluid to be pumped.

There are two consequences of this. Firstly, the radial load on the bearings of the machine is low. Secondly, there is self-lubrication at each point of contact due to the leaks between high pressure and low pressure. This self-lubrication should in particular facilitate the starting of the machine, without any sticking effect.

Furthermore, the osculating contact on the appearance and disappearance of the chambers at the bifurcations B_N and B_M respectively, results firstly in each chamber appearing and disappearing on a relatively large contact area, and secondly with a very slow growth in volume. These two circumstances facilitate the creation of orifices of the appropriate size to start the supply and end the discharge of each chamber,

as it appears and as it disappears respectively, as will be seen below.

Figures 2A to 2F show six successive angular positions of the two profiled members 1 and 2 of the machine in figure 1, from the situation shown in figure 1, which is also the situation shown in figure 2A. The situation shown in figure 2F corresponds to chamber V_4 passing through its maximum volume. These views in particular allow for the development of the chamber, which forms at point B_N in figure 2A, to be followed. It can also be seen how chamber V_9 in figure 2A disappears at bifurcation point B_N in figure 2C.

The example in figure 3 will only be described in terms of its differences relative to the example in figure 1.

The m-lobed profile 13 is now outside the (m-1)-lobed profile 14, and belongs to a profiled member 11 that is outside and surrounds the profiled member 12 with the (m-1)-lobed profile 14.

This time, there are two curves of action CB_2 and CB_3 radially beyond the rolling point R and a single curve of action CB_1 on the other side of the tangent T. The curves of action are concurrent at bifurcation points B_N and B_M situated on the common tangent T as previously, except that the bifurcation B_N, which corresponds to the appearance of the chambers, is now situated higher up relative to the direction F of rotation taken as an example, relative to the bifurcation B_M, which corresponds to the disappearance of the chambers. Beyond point B_M, the chambers V_2, V_3 and V_4 are all growing and then the chambers V_5, V_6 and V_7 are shrinking whilst a new growing chamber is appearing by osculation at point B_N in the situation shown. There is therefore only alternation of growing and shrinking chambers radially beyond the tangent T. There are fewer points of contact than in the machine in the first class in figures 1 and 2A to 2F.

Figures 4A to 4F show six successive states of the machine in figure 3, from the situation

shown in figure 3, which is also the situation shown in figure 4A.

In the situation shown in figure 4F, the chamber V_4 has reached a position in which it is symmetrical relative to the axis Ox so that the direction of change in its volume is changing. This is why this figure also shows inlet ports 8 and discharge ports 9 made through a flange which, moreover, laterally closes the chambers. The chamber V_4 does not communicate with the port 8 or the port 9. The chambers in the growth phase communicate with the port 8, which extends to the rear point of contact C_4 of the chamber V_4. The chambers in the shrinkage phase communicate with the discharge port 9, which starts from the front point of contact C_5 of the chamber V_4. The flange(s) in which the ports 8, 9 are made is/are securely attached to the connecting member represented by the reference Oxy.

The specific parameterisation allowing for the implementation of the geometric profile definitions according to the invention will now be described with reference to figure 5.

The circle with a centre 0 and a radius 1, intended to form the pitch circle of the m-lobed profile, is considered in the Euclidean plane. The arc M_0M_π is chosen arbitrarily; in the example in figure 5 it is shown as identical to the dome of a lobe of the profile 3, including with regard to its distance and orientation relative to the centre O, and a radius issuing from this centre. The expression "is chosen arbitrarily" is not given to mean that any arc will do, and necessary conditions that this choice must meet will be given below. Apart from the types of arc to be ruled out, the shape and dimension of the arc can also be chosen, together with its position relative to the centre O depending on desiderata relating to the geometry sought, taking into account for example the different examples of geometry shown and described below. The arc M_0M_π is known as the "given arc", and any point on the given arc is known as M. One of the characteristics that the given arc

must have is that its normals N_0 and N_π to the extremities M_0 and M_π are tangent to two different points of the pitch circle 6.

The two intersections of the normal to the arc at M with the pitch circle 6 are known as P and D, point P being situated between M and D. The middle of the segment PD is further known as N. The angle DOP, measured clockwise between 0 and 2π, is known as 2δ, so that δ is between 0 and π. The polar angle of P minus δ, which is also the polar angle of D plus δ is known as σ. It can be seen that for $\delta < \pi/2$, σ is the polar angle of N and that for $\delta > \pi/2$, σ is the polar angle of the point of symmetry of N relative to the origin O.

Finally, the distance MN counted positively is known as ρ.

The values (δ, σ, ρ) are defined univocally by the point M. Reciprocally, the point M is defined univocally by these values; the half-line with origin O and polar angle σ is constructed, and then the points P and D by taking the angles $\pm\delta$ from this half-line. The point N is the middle of the segment PD and M is constructed by plotting the length MN = ρ on the straight line PD from the side of P.

The given arc is chosen as being a differentiable arc on which the angle δ is a coordinate between 0 and π. This means that when the point M moves along the arc, the angle δ associated with it takes each value between 0 and π once and once only. We are therefore interested in arcs the normal of which regularly brushes (from a tangent N_0 to a tangent N_π) the pitch circle, when they are moved along from the origin to the extremity. These arcs form two classes in the relative direction of travel and brushing, and these two classes are associated with the two aforementioned classes of conjugate profiles and therefore of machines.

In choosing δ as a parameter along the arc, the arc is characterised by the two functions $\rho(\delta)$ and $\sigma(\delta)$.

These two functions are not independent; they are connected by the following relationship between their derivatives $\rho'(\delta)$ and $\sigma'(\delta)$ relative to δ:

$$\sigma'(\delta)\cos(\delta) = \rho'(\delta)$$

The addition of a constant to the function $\sigma(\delta)$ corresponds to an overall rotation of the arc around the origin O. Because in conjugation problems, we are interested in arcs defined to within such a rotation, it is natural to characterise the arcs by the function $\rho(\delta)$, with the function $\sigma(\delta)$ being deduced by the quadrature:

$$\sigma(\delta) = \int_{\delta 0}^{\delta} \frac{\rho'(\tau)d\tau}{\cos(\tau)}$$

this integration being carried out from $\tau = \delta_0$ to $\tau = \delta$, where τ is a dummy variable of integration and the arbitrary on the constant of integration δ_0 corresponds to an arbitrary rotation of the arc around the origin O.

With these definitions, the Cartesian coordinates $(x(\delta), y(\delta))$ of an arc defined by the function $\rho(\delta)$ and a choice of the constant in $\sigma(\delta)$ are written:

$$x(\delta) = \cos(\delta)\cos(\sigma(\delta))+\rho(\delta)\sin(\sigma(\delta))$$

$$y(\delta) = \cos(\delta)\sin(\sigma(\delta))+\rho(\delta)\cos(\sigma(\delta))$$

Given an arc defined as above by the function $\rho(\delta)$ and an integer $m\geq 2$, its four associated arcs are defined by the following expressions:

- proximal conjugate arc:

$$x_{CjP}(\delta) = (1 + (\sin(\delta) - m\rho(\delta))\sin\left(\frac{\delta - m\sigma(\delta)}{m - 1}\right) + (m-1)\cos(\delta)\cos\left(\frac{\delta - m\sigma(\delta)}{m-1}\right))/m$$

$$y_{CjP}(\delta) = ((\sin(\delta) - m\rho(\delta))\cos\left(\frac{\delta - m\sigma(\delta)}{m - 1}\right) - (m-1)\cos(\delta)\sin\left(\frac{\delta - m\sigma(\delta)}{m-1}\right))/m$$

- distal conjugate arc:

$$x_{CjD}(\delta) = (1 + (\sin(\delta) + m\rho(\delta))\sin\left(\frac{\delta + m\sigma(\delta)}{m - 1}\right) + (m-1)\cos(\delta)\cos\left(\frac{\delta + m\sigma(\delta)}{m-1}\right))/m$$

$$y_{CjD}(\delta) = (-(\sin(\delta) + m\rho(\delta))\cos\left(\frac{\delta + m\sigma(\delta)}{m - 1}\right) + (m-1)\cos(\delta)\sin\left(\frac{\delta + m\sigma(\delta)}{m-1}\right))/m$$

- proximal complementary arc:

$$x_{CpP}(\delta) = ((2\sin(\delta) - m\rho(\delta))\sin\left(\frac{2\delta}{m} - \sigma(\delta)\right) + m\cos(\delta)\cos\left(\frac{2\delta}{m} - \sigma(\delta)\right))/m$$

$$y_{CpP}(\delta) = ((2\sin(\delta) - m\rho(\delta))\cos\left(\frac{2\delta}{m} - \sigma(\delta)\right) - m\cos(\delta)\sin\left(\frac{2\delta}{m} - \sigma(\delta)\right))/m$$

- distal complementary arc:

$$x_{CpD}(\delta) = ((2\sin(\delta) + m\rho(\delta))\sin\left(\frac{2\delta}{m} + \sigma(\delta)\right) + m\cos(\delta)\cos\left(\frac{2\delta}{m} + \sigma(\delta)\right))/m$$

$$y_{CpD}(\delta) = (-(2\sin(\delta) + m\rho(\delta))\cos\left(\frac{2\delta}{m} + \sigma(\delta)\right) + m\cos(\delta)\sin\left(\frac{2\delta}{m} + \sigma(\delta)\right))/m$$

A pair of conjugate profiles is defined from a given arc defined by the function $\rho(\delta)$ and the associated arcs.

As mentioned above, there are two classes of such profiles, which correspond to the two relative directions of brushing of the circle by the normal to the given arc, moving along this arc.

These two classes are very simply characterised by the sign of the derivatives $\rho'(0)$ and $\rho'(\pi)$.

One of the profiles is generated by the concatenation (that is, placing end to end whilst keeping the relative orientation) of the given arc and one of the complementary arcs: this is the complemented profile; the other is generated by the concatenation of the two conjugate arcs: this is the conjugate profile.

The given arc is in the first class when: $\rho'(0) > 0$ and $\rho'(\pi) < 0$.

An examination of the regularity of the connections shows that the following is more specifically required:

$1/m > \rho'(0) > 0$ and $-1/m < \rho'(\pi) < 0$

In this case, the complemented profile is formed by the concatenation of the given arc and the proximal complementary arc, repeated by rotations of $2\pi/m$ around the origin. The profile is of order m, that is, it is maintained by the rotation of $2\pi/m$ (around the origin) and it has m lobes or teeth. This is the profile shown partly in figure 5.

The conjugate profile is formed by the concatenation of the proximal conjugate arc and the distal conjugate arc, repeated by rotations of $2\pi/(m-1)$ around the centre O′ with coordinates $(1/m, 0)$. The profile is of order $(m-1)$, in the same direction as previously. The ratio of the rotation speeds is $(m-1)/m$.

The complemented profile is inside the conjugate profile.

The given arc is in the second class when: $\rho'(0) < 0$ and $\rho'(\pi) > 0$.

An examination of the regularity of the connections shows that the following is more specifically required:

$-1/m < \rho'(0) < 0$ and $1/m > \rho'(\pi) > 0$

In this case, the complemented profile is formed by the concatenation of the given arc and the distal complementary arc, repeated by rotations of $2\pi/m$ around the origin. The profile is of order m.

The conjugate profile is formed, as for the first class, by the concatenation of the proximal conjugate arc and the distal conjugate arc, repeated by rotations of $2\pi/(m-1)$ around the centre O′ with coordinates $(1/m, 0)$. The profile is of order $(m-1)$. The ratio of the rotation speeds is $(m-1)/m$.

The complemented profile is outside the conjugate profile.

The inequalities relating to $\rho'(0)$ and $\rho'(\pi)$ are strict. This point controls the continuity of the curvature of the profiles at the connections between the arcs.

These inequalities are necessary and sufficient for the regularity of the connections, but do not ensure the regularity of the arcs themselves, which must be examined elsewhere. In other words, any $\rho(\delta)$ function does not necessarily lead to a pair of regular conjugate profiles.

Below is some information about regularity at the inner points of the associated arcs.

It can be demonstrated that the only singularities likely to appear on the arcs associated with a regular given arc are of the swallowtail type: two cusps surrounding a self-intersection. The condition

for this not to occur is simply that the speed vector (vector derived from the current point on the arc relative to the parameter) is not cancelled over the interval $]0,\pi[$. These four speeds (corresponding to the four arcs from which the two profiles are formed) are expressions dependent on δ, $\rho(\delta)$ and the derivative $\rho'(\delta)$. The non-cancellation of these expressions is therefore a constraint on the function $\rho(\delta)$. This constraint must be approached from the angle of verification, unless the systems of non-linear differential inequations can be solved. For the given arc, the condition on the amplitude of the speed is written:

$$V(\delta) = (\rho(\delta)\rho'(\delta))/\cos(\delta)-\sin(\delta)\neq 0$$

and this condition simply expresses that the quotient by $\cos(\delta)$ of the derivative of the square of the radius vector keeps a constant sign.

The corresponding expressions for the associated arcs are less simple. They are as follows:

for the proximal complementary arc:

$$V_{CpP}(\delta) = (m\rho(\delta)-2\sin(\delta))\rho'(\delta)/(m\cos(\delta)) - (2m\rho(\delta)+(m^2-4)\sin(\delta))/m^2 \neq 0$$

for the distal complementary arc:

$$V_{CpD}(\delta) = (m\rho(\delta)+2\sin(\delta))\rho'(\delta)/(m\cos(\delta)) - (2m\rho(\delta)-(m^2-4)\sin(\delta))/m^2 \neq 0$$

for the conjugate arcs:

$$V_{CjP}(\delta) = (m\rho(\delta)-\sin(\delta))\rho'(\delta)/((m-1)\cos(\delta)) - (\rho(\delta)+(m-2)\sin(\delta))/(m-1) \neq 0$$

$$V_{CjD}(\delta) = (m\rho(\delta)+\sin(\delta))\rho'(\delta)/((m-1)\cos(\delta)) + (\rho(\delta)-(m-2)\sin(\delta))/(m-1) \neq 0$$

An interesting family of pairs of profiles in the first class is obtained from arcs of shortened epicycloids. These are in fact typical solutions, more than an example.

These arcs depend on three parameters: n is the order of the epicycloid, which can be chosen as real (positive and not too small), φ is an angular parameter of between 0 and $\pi/2$, which describes the shortening (or eccentricity), and finally ρ_0 is the parallelism parameter, that is, a

parameter characterising the distance to the base epicycloid. The calculation of $\rho(\delta)$ and $\sigma(\delta)$ gives:

$$\rho(\delta) = (1-1/n)(1/\cos(\varphi)^2)-\cos(\delta)^2)^{1/2}+(1/n)\sin(\delta)+\rho_0$$

$$\sigma(\delta) = (1-1/n)\arccos(\cos(\delta)\cos(\varphi))+(\delta/n)$$

The best osculation of the profiles is found for n close to 2m-2; ρ_0 must not be too far from 0; small φs correspond to fine teeth and when φ tends towards $\pi/2$, the profiles become rounder and larger without limitation; reasonable values for φ are around $\pi/3$ or $\pi/4$.

A family of examples of profiles in the second class is similarly provided by:

$$\rho(\delta) = (1+1/n)(1/\cos(\varphi)^2- \cos(\delta)^2)^{1/2}-(1/n)\sin(\delta)-\rho_0$$

$$\sigma(\delta) = (1+1/n)\arccos(\cos(\delta)\cos(\varphi))-(\delta/n)$$

The variability of the parameters (before a singularity is encountered) is greater than in the previous case, particularly with regard to ρ_0.

To sum up, the given arc must have the following property: when it is moved along from its origin to its extremity, its normal "regularly brushes" the pitch circle, and in particular, the normals to the origin and the extremity of the arc are tangent to the pitch. The possible arcs are split into two disjoint classes: those with a normal that brushes the pitch circle "in the opposite direction" to the current point M and those with a normal that brushes it "in the same direction" as the current point M.

The two classes of solutions already discussed with regard to the problem of maximum inner conjugation correspond to these two possibilities. The first class is made up of pairs of profiles such that the inner profile has one more lobe than the outer profile; the second class, conversely, is such that the inner profile has one lobe fewer than the outer profile. These two classes have very different morphologies and properties as described above.

In general, the formulae obtained for the arcs are nonsingular, in that

the family of the four arcs that define the two profiles can be constructed from any one of them. This does not mean that they play completely symmetrical roles: in fact, of the two arcs that form each profile, one of the two comes into contact with both arcs of the other profile, and the other with just one of them. Such is the maximum conjugation, as a result of which the curves of action are formed from three arcs concurrent at two bifurcation points B_M and B_N. The contact passes through these "triple points" at the connection between the two arcs that form each of the two profiles.

The parameterisation according to the invention has allowed for simple mathematical expressions for the curves of action to be determined for the machines according to the invention, namely:

- the contact between the given arc and its proximal conjugate is the proximal curve of action, with the following equation:

$$x(\delta) = 1-\sin(\delta)(\sin(\delta)-\rho(\delta))$$

$$y(\delta) = \cos(\delta)(\sin(\delta)-\rho(\delta))$$

- the contact between the given arc and its distal conjugate is the distal curve of action, with the following equation:

$$x(\delta) = 1-\sin(\delta)(\sin(\delta)+\rho(\delta))$$

$$y(\delta) = -\cos(\delta)(\sin(\delta)+\rho(\delta))$$

- the contact between the proximal complementary of the given arc and its proximal conjugate is the proximal complementary curve of action, with the following equation:

$$x(\delta) = 1-\sin(\delta)(((m-2)/m)\sin(\delta)+\rho(\delta))$$

$$y(\delta) = -\cos(\delta)(((m-2)/m)\sin(\delta)+\rho(\delta))$$

- the contact between the distal complementary of the given arc and its distal conjugate is the distal complementary curve of action, with the following equation:

$$x(\delta) = 1-\sin(\delta)(((m-2)/m)\sin(\delta)-\rho(\delta))$$

$$y(\delta) = -\cos(\delta)(((m-2)/m)\sin(\delta)+\rho(\delta))$$

These four arcs are concurrent at points $\delta = 0$ and $\delta = \pi$. The proximal and distal complementary curves of action pass radially beyond the rolling point R, and the

other two on the other side of the origin O relative to the rolling point R. Only three of these four curves of action intervene: the distal complementary curve of action is absent for the first class, for which the distal complementary arc does not intervene, and the proximal complementary curve of action is absent from the second class, for which the proximal complementary arc does not intervene.

Figures 7A, 7B, 8A, 8B, 9A and 9B show different embodiments of machines in the first class. It appears that when the number of lobes is small, for example 2 or 3, the lobe hollows are simply less protruding areas, the profile of which can even be convex with regard to the inner profiled member.

In the very specific case in which the (m-1)-lobed profile only has one lobe (figures 7A and 7B), the lobe vertex and the lobe hollow are diametrically opposed, if the profile is symmetrical.

Figures 10A to 10I show nine variants of geometries for a four-lobed inner profile in a three-lobed profiled outer member.

Figures 11A to 11C show three examples of a machine in the first class with a five-lobed inner rotor.

The embodiment in figure 11B is characterised by the fact that the two osculating contacts occur simultaneously, on either side of a chamber V_1, the volume of which is then at its maximum.

By comparison, the embodiment in figure 11A is analogous to the embodiment in figure 1, in that a chamber V_2 the rear edge of which has passed the bifurcation point B_M and behind which a chamber V_1 has therefore disappeared, has not yet reached with its front edge the other bifurcation point B_N, at which a future new chamber V_3 will appear in front of it, which is therefore only shown with a dashed line.

Conversely, in the embodiment in figure 11C, the same chamber V_2 covers both bifurcation points B_N, B_M at the same time, so that it is still followed by

a disappearing chamber V_1 and is already preceded by an appearing chamber V_3.

A method of distribution for a machine, in particular a hydraulic machine, in the first class, will now be described with reference to figure 12.

Figure 12 relates to the machine in figure 11B. It is considered that there is a flange against each radial surface of the profiled members 1 and 2 laterally closing the chambers, with the exception of the ports that will be described. These flanges are firmly rotatably attached to the outer profile 2. In the flange located on the side of the observer in figure 12, teardrop- or comma-shaped ports 16, the angular tip of which coincides with the connection of the two arcs forming the outer profile, on the rear side of the lobes, have been formed through the flange (the flange itself is not shown).

From their tip coinciding with the connection of the arcs forming the profile 4, the ports extend generally towards the axes O and O'. These ports 16, depending on whether or not they are covered by the m-lobed profiled member, selectively make the chambers communicate with the intake. In the other flange, located at the axial extremity hidden from the observer in figure 12, there are ports 17 that are symmetrical with the ports 16 relative to radii passing through the lobe vertices of the (m-1)-lobed profile 4, and the angular tip of which coincides with the connection between the two arcs forming the (m-1)-lobed profile 4 on the front side of each lobe. The ports 17 communicate with the hydraulic discharge of the machine.

By means of the particularity of the geometry shown, according to which the chamber V_1 is adjacent on one side to a disappearing chamber at point B_M and on the other side to a chamber appearing at point B_N, the chamber V_1 is only isolated for a short instant when its volume is at its maximum and is therefore not varying. In the previous instant, the disappearing chamber was still communicating with the

neighbouring discharge port 17 whilst the chamber V_1 was communicating with the inlet port 16. In the next instant, the new chamber will communicate with the corresponding inlet port 16, whilst the chamber V_1 will communicate with the discharge port 17.

Figure 12A shows that instead of or in addition to the ports 16 and 17, inlet channels 18 and discharge channels 19 can also be provided in the (m-1)-lobed profiled member, opening through the respective sides of the lobes of the outer profile 4, approximately at the connections between the two arcs forming the profile 4 so that they are closed when the profiles are in osculating contact and are then progressively opened by the chamber forming between the two contacts resulting from the disintegration of the osculating contact, in the case of the appearance of a chamber for the intake, or are progressively closed with regard to the discharge, in the case of the disappearance of a chamber.

In the example shown in figure 13, the machine has a geometry corresponding to the geometry in figure 1, apart from the number of lobes. The situation is also the situation shown in figure 11A, but when the profiled members 1 and 2 are at a different angle around their respective axes.

The situation shown in figure 13 corresponds approximately to the situation in figure 2A. Looking at figure 2D, it can be seen that the chamber V_4, the rear edge of which has already passed bifurcation point B_M and would consequently already be communicating with the discharge port in a distribution system according to figure 12, has still not reached point B_N and would therefore still be communicating with the inlet port of such a distribution system, which is moreover necessary as the volume of the chamber V_4 is still growing. It is therefore the communication with the discharge port that must be eliminated. A mask 21 firmly attached to the housing (the connecting member) is therefore provided for in figure 13, extending over a certain angular distance forwards relative to the direction of

rotation defined by the arrow F, from the bifurcation point B_M, to close the discharge port in this area.

For entirely symmetrical reasons, a mask 22 is provided to close the inlet ports over a certain angular area from the bifurcation point B_N backwards relative to the direction of rotation.

In the situation shown in figure 11C, the chamber V_2 undergoes variations in volume between the time when its front edge covers the bifurcation point B_N and until its rear edge no longer covers the other bifurcation point B_M.

In this angular range, the chamber V_2 would no longer communicate with any of the ports in a distribution system such as the one in figure 12. To overcome this difficulty, additional connections, controlled for example by a cam when a chamber such as V_2 passes into this area, or other analogous solutions, are in principle necessary.

Figure 14 shows a particularly preferred embodiment of a machine with a profile according to figure 1. The distribution principle is the same as in figure 12, and in each plane perpendicular to the axes the profiles 3 and 4 are those in figure 1. However, from one plane to another, each profile 3 or 4 is angularly displaced by a given pitch around its respective axis in order to give all of the profiled members a helical appearance. The angular displacement between the profiles of the two extremities is such that in the situation shown, where the chamber V_5 on the intake side is reaching the bifurcation point B_N, the rear edge of this chamber, which itself has a helical appearance, has just left the other osculation at the other bifurcation point B_M. The situation that was obtained by a profile in a single plane in the cases of figures 11B and 12 is therefore restored by means of helicity, namely that the same cavity is adjacent to an appearing cavity at its front edge and a disappearing cavity at its rear edge. This cavity V_5 is therefore

only isolated for a short instant when the instantaneous speed of variation in its volume is equal to zero. In figure 14, the vertices of the profile 3 of the profiled inner member are shown with solid lines and some of the vertices of the lobes of the profile of the outer profiled member 4 are shown with a dash and cross line. The centres O and O′ of the profiles of the successive planes are aligned along parallel axes of rotation that are also parallel to a straight line R_R on which the rolling points R are aligned.

Figure 15 schematically shows an embodiment of a machine in the first class according to the invention. The profiled inner member 1 is firmly attached to a drive shaft 23 that is driving in a pump and consuming in a hydraulic motor. The shaft 23 is rotatably supported, on either side of the profiled member 1, by two bearings 24 in a fixed housing 25 that forms the connecting member according to the invention. The profiled outer member 2 is rotatably supported by peripheral bearings 26 installed between the outer peripheral wall of the profiled member 2 and a peripheral ring gear 27 forming part of the housing 25. The centre line of the shaft 23 corresponds to the centre O whilst the centre line, not shown, of the bearings 26 corresponds with the centre O'. In the area in which the profiles 3 and 4 are formed, the profiled members 1 and 2 are installed between two flanges 28, 29 through which the inlet ports 16 and discharge ports 17 are respectively formed.

The profiled members 1 and 2 have flat, coplanar end surfaces on which corresponding flat end surfaces of the flanges 28 and 29 rest tightly and slidably in order to close the chambers apart from with regard to the communications established selectively by the ports 16 and 17.

Between each flange 28 or 29 and a corresponding end wall 31 or 32 of the housing, there is a respective axial stop 33, 34. The flanges 28, 29 are connected rotatably with the profiled outer member 2 whilst being translatably free relative to the latter by means of

splines 36. The inner space contained between the end wall 31 of the housing on the one hand and the flange 28 and the corresponding surface of the profiled member 1 on the other hand is formed into a chamber subject to the inlet pressure. Similarly, a chamber subject to the discharge pressure is formed between the other end wall 32 of the housing on the [one] hand and the other flange 29 and the other end surface of the profiled inner member 1 on the other hand. These two chambers are closed by dynamic sealing devices 38, 39, 41, 42 that prevent the hydraulic fluid from reaching the bearings 24 and 26, and prevent the two chambers from communicating with each other between the outer profiled member 2 and the ring gear 27 of the housing.

In service, whichever of the two chambers is subject to high pressure (the inlet in the case of a motor and the discharge in the case of a pump) compresses the axial stack formed by the two flanges and the two profiled members 1 and 2 mounted sandwiched between them, resting axially against the axial stop of the opposite chamber. The area exposed to the pressure to provide this axial pressing force is chosen so that the axial thrust is appropriate to achieve a seal between the flanges and the profiled members, but without being excessive.

Furthermore, if the profiled members are helical as described with reference to figure 14, the axial thrust thus created must be sufficient to balance the tendency of the profiled members to become "unscrewed" relative to each other under the action of the working forces exerted between the profiles 3 and 4.

For example, if with the embodiment shown in figure 15 the axial thrust selected is too great, the sealing devices 41 and 42 shown as acting on contact with the shaft 23 can be moved radially outwards beyond the axial stops 33 and 34, therefore between each flange and the corresponding end wall 31 of the housing. Furthermore, the shaft 23 must be mounted with a certain freedom of axial slide to

allow for the axial wandering of the profiled member 1 between the flanges 31 and 32. The profiled outer member 2 is free to rotate so that its driving results from its cooperation with the profiled member 1 and the working fluid.

In the example shown in figure 16, the machine is a variable capacity machine. For this, the profiled members 1 and 2 slide axially relative to each other. In the example shown, the profiled member 2 is fixed axially, resting against the housing 25 by means of an axial stop 53 and a flange 51. The profiled member 1 slides axially relative to the housing by means of an actuator 49 that is only schematically shown, acting on the member 1 by means of an axial stop 54 and a flange 52. The flange 51 rests tightly against a flat end surface of the outer profiled member 2 and has as a radially inner edge a profiled surface 47 that is exactly complementary to the profile 3 of the profiled member 1. Thus, the flange 51 is in tight contact with the profile 3 around the entire circumference of the profiled member 1, to slide axially relative to the profiled member 1 whilst being driven rotatably by the profiled member 1.

Similarly, the flange 52 is resting tightly against a flat end surface of the profiled member 1 and has on its outer circumference a profiled surface 48 that is exactly complementary to the profile 4 of the profiled member 2 so that it rests tightly on it, sliding axially, and ensuring the rotation of the flange 52 with the profiled member 2. The distribution is ensured by the channels 18, 19 according to the embodiment in figure 12A.

Figures 17A to 22B show various embodiments, each in two operating states, of machines in the second class, with numbers of lobes ranging from one for the profiled inner member and 2 for the profiled outer member (figures 17A and 17B) to 7 for

the profiled inner member and 8 for the profiled outer member (figures 22A and 22B).

By comparison with the embodiment in figures 19A and 19B, when the profiled inner member is tri-lobed and the profiled outer member is four-lobed, figures 23A to 25B show three other possible geometries that illustrate the great variety of the geometries that can be achieved for the machines in the second class.

For the machines in the second class, there are two curves of action on the side of the rolling point and just one on the opposite side. The outer curves are simple arcs. The inner curve may have a loop, the double point of which the rolling point; this is not a singularity of the profiles. At the moment when the contact passes through the rolling point, the relative movement of the two profiles is rolling without sliding. In borderline cases for which the curve of action has a cusp point at the rolling point, the speed of the point of contact is cancelled at this point.

The description of the chamber cycle is slightly complicated by the possible occurrence of the phenomenon of "chamber splitting" described briefly below. In any case, a chamber appears when the front sides of the lobes of the outer profile pass through the osculating contact, at the intersection B_N of the curves of action situated above the axis Ox containing the point R. It passes through its maximum after a rotation of just over a half-revolution. The chamber is then on the opposite side to the rolling point relative to the pivots. The closing of the chamber is symmetrical with its opening, and the "lifetime" of the chamber is a little greater than one revolution.

The phenomenon of chamber splitting might arise for chambers close to their appearance or disappearance, that is, when two lobes are strongly engaged with each other on the side of the rolling point. The volumes of the chambers in question are small. The sequence is as follows: at a point inside a closing chamber, the two profiles reach

an exceptional osculating contact, and the chamber is split into two sub-chambers. The new osculating contact disintegrates into two simple contacts between which a new chamber appears. Each of the two contacts meets the corresponding edge of one of the two closing sub-chambers and they disappear (generally at different moments), one in a normal way when it passes through the confluence of the curves of action, and the other in an exceptional way through an osculation that disappears on the spot. At this point, the new chamber coalesces with another new chamber that appears normally at the bifurcation of the curves of action.

This slightly difficult phenomenon of chamber splitting takes place if the profiles become tangent to the outer curve of action on the side of the rolling point, but outside the axis Ox.

Figures 26A and 26B show a particularly appropriate geometry for the production of a compressor. It is a machine in class two, with a bi-lobed profiled inner member and a tri-lobed profiled outer member. A machine of this type and more generally a machine according to the invention has the following advantageous specific features for the production of a compressor, both of which contribute to limiting leaks:

- the chambers are completely emptied; a single flap valve can therefore be used to eliminate backflow towards the low pressure;
- the relative curvature of the surfaces in "contact" (generally, these machines are not self-driven and contact is not reached) is limited; leaks therefore occur through a passage that is not only as narrow as manufacturing precision allows, but also remains narrow over a certain length.

The aim is to raise as many obstacles as possible between the low pressure side and the high pressure side of the compressor. It is therefore natural to turn the attention more to the second class of conjugate profiles; during the growth phase, the consecutive chambers remain at the

inlet pressure, and during the volume shrinkage phase, compression is progressive. It is only at the end of compression that the closing chamber is adjacent to two low pressure chambers: along the outer curve of action with an appearing chamber and along the inner curve of action with a growing chamber. In both cases, the concavities of the surfaces in contact are in the same direction and the relative curvature is small (it is cancelled at the end of discharge). A profile that does not give rise to chamber splitting, such as the one in figures 26A and 26B, will be chosen.

The helical embodiment is possible and gives the same high quality of contact as the straight embodiment.

For a compressor, it may be preferred to keep the outer profile fixed (which then becomes the profile of the housing) and give the rotor a planetary movement; the connecting member is then rotating relative to the housing around the axis 0 of the profiled outer member.

In a compressor, the properties of the fluid also change between intake and discharge; in addition, the parameters to be optimised are not the same on intake (limitation of pressure loss) and on discharge (limitation of leaks). For these reasons, it may be preferred to use asymmetrical profiles. An example of this is given in figures 27A and 27B.

In the example shown in figures 28A to 28F, an intermediate profiled member 62 comprises a first profile 64 of order m-1 on its radially inner surface, and a second profile 74 of order (m-1) on its radially outer surface. The two profiles have the same pitch circle centred on O'. Each of the (m-1)—lobed profiles 64, 74 cooperates with an m-lobed profile 63, 73 of a profiled member 61 that is shown fixed in this example. The two profiles 63, 73 also have a common pitch circle, which is centred on O. The profiles 63 and 64 form a machine in the first class according to the invention and the profiles 73 and 74, a machine in the second class according to the invention.

In the example shown in figures 29A to 29F, the difference is that the intermediate profiled member 82 has two m-lobed profiles cooperating with two (m-1)-lobed profiles belonging to a profiled member 81.

Such geometry could allow for the production of an internal combustion engine in which, for example, the inner machine would be used for intake and compression, whilst the outer machine would be used for expansion and exhaust.

Of course, the invention is not limited to the examples described and shown.

In the examples described, and more particularly in the example in figure 15, the profiled inner member is driven rotatably and the profiled outer member rotates due to the torque transmitted at the contact points between the profiled inner member and the profiled outer member, which rotates freely in the housing. Furthermore, during operation as a motor, the pressure of the hydraulic fluid tends to cause the cavities subject to this pressure to move towards an increase in their volume, which contributes to forcing the profiled outer member in the desired direction of rotation. However, provision could also be made for an external drive, for example by gearing, that forces the two profiled members to rotate in a speed ratio corresponding to the ratio of the number of their lobes. Equally, the profiled outer member could be driven and the profiled inner member left free. One of the two profiled members can further be fixed to the housing and the other profiled member driven in a planetary movement by rotating the centre of the pitch circle of the other profiled member around the centre of the pitch circle of the fixed profiled member. In this configuration, said other profiled member can be left to position itself freely around its own axis or on the contrary, its angular position can be determined, for example by gearing, as a function of the angular position of the connecting member around the centre of the fixed profiled member.

The invention is compatible with the Moineau principle by which, as described in US-A-1 892 217, the helical shape of the two profiled members extends over sufficient pitches so that no cavity opens simultaneously at the two axial ends of the machine. Due to the accuracy and quality of the geometry according to the invention, it is possible to limit the total angular displacement between the profiles at the two ends of the machine to a value hardly greater than the lifetime of the chamber in each plane perpendicular to the axes.

The pitch is not necessarily the same throughout the machine, and the profile can further be varied along the axes of the machine. This allows for example for the production of a compressor or an expansion motor in which the volume of the transferring chambers varies progressively.